technical guide

How to use the

DRYIT

Semi - continuous Tray Dryer

By

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How to use the *DRYIT* semi-continuous tray dryer

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Preface

Some years ago, Practical Action, then known as ITDG, received a letter from a businessman in Colombia, South America asking if ITDG knew of any low-cost, controllable Dryers suitable for herbal teas. While he felt sure that there was a market for these products in his country, as imported brands were widely on sale, he was however unable to convince his bank that it was possible to produce dried teas able to compete in terms of price, quality and presentation. His loan request for $40,000 to purchase an imported dryer was thus rejected.

By good luck ITDG had just prepared the first draft drawings for the construction of what is now called the *DRYIT* semi-continuous tray dryer. These were sent to the enquirer and a unit was built at a cost of $4000. The company was soon able to get into production and now, the company is still in operation, running two dryers. Imported herbal teas have now almost been displaced from the market. This short story illustrates the key objective of ITDG's *DRYIT* programme and range of small industry dryers that are:

- Low cost
- Controllable
- Can be largely built locally
- Provide an ideal test system to investigate both pre drying (farm production, sanitation etc) and post drying aspects (packing, presentation, marketing and economics)

Preserving a crop or food by drying it is probably the most common method used worldwide. A whole range of drying methods are used from the simplest-laying the product out in the sun, to complicated systems such as spray and freeze-drying. The choice of system used depends on a number of factors the most important of which are:

- The nature of the product being dried
- The scale of operation
- The cash value being added through drying the local climate
- The demands in terms of quality of buyers

One particularly common method used in small industry is tray drying in which the food is placed in trays with a mesh bottom through, or over which, heated air is passed. Small tray Dryers are commercially available and basically consist of a box full of trays and a source of hot air. Such commercial units, which in general have to be imported, tend to be too expensive for small businesses in developing countries - a typical half-ton dryer now costs $85,000.

There are three models of *DRYIT* dryers the *Batch Dryer*, the *Medium Semi-continuous Tray Dryer* and the *Semi-continuous Tray Dryer*. These are described in more detail later.

This guide is part of a technical information package aiming to help small businesses; whether group or private, to gain access to information to help build and use such dryers should they feel them appropriate to their needs.

In view of the wide range of applications, climatic variations in different countries, quality standards required etc general publications can't cover all options and possibilities. Practical Action however can, through its technical enquiry service, provide individual advice and backup to interested users.

We need your help as well!

If you are involved in small-scale drying of foods or crops your experiences are important to us at Practical Action and will help further develop appropriate systems and methods that may benefit someone elsewhere in the world.

If you have any questions or comments please contact one of the Practical Action offices.

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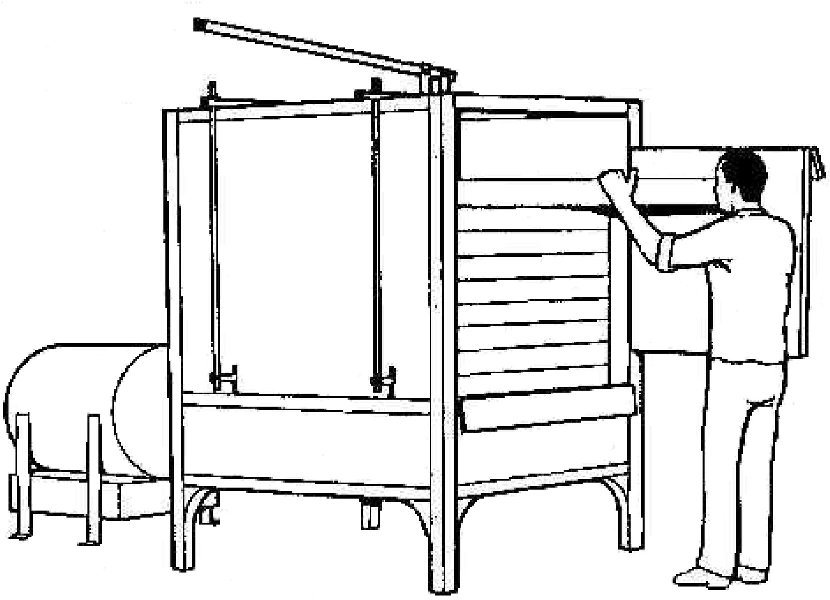

Figure 1: Tray dryer in use

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Introduction

What is the difference between batch and semi-continuous drying?

A batch dryer consists of a large box or chamber with internal runners that support a number of trays. Heated air is blown into the chamber, usually by a kerosene or gas fired heater blower. In use the trays are loaded with the product and placed in the drying chamber. The doors are closed and the heater turned on and left running until all the product is dry. Most people using batch drying operate on a 10-hour drying cycle as this allows two batches a day to be processed.

In a batch dryer the trays at the bottom, that is nearest the source of hot air, dry first and as drying proceeds those higher up the stack dry. The trays at the very top do not dry till the end of the 10-hour period. This gives rise to two main problems.

- Some material, particularly that at the bottom, may over dry or be affected by being hot for such a long time.
- The air leaving the dryer outlet becomes dryer and dryer and hotter and hotter as the drying cycle proceeds. In other words, fuel is being wasted.

A semi-continuous dryer attempts to overcome these problems. Again it consists of a drying chamber and heater but is fitted with a mechanical system that allows the removal of the bottom tray when it is dry, automatic lowering of the remaining trays and the insertion of a new tray of raw material at the top of the tray. While this is clearly an advantage over batch drying. The semi continuous system also has three main disadvantages:

- The cabinet is more expensive and complex
- Semi-continuous drying involves 24-hour operation.
- Labour requirements are higher

We can sum up the relative advantages and disadvantages of the two systems as follows.

Batch	Very simple to build Low cost Low labour cost, simply fill and empty Uses more fuel Some material may be over dried Product may deteriorate
Semi Continuous	More expensive and complex to build Ideally requires 24-hr operation. Better fuel efficiency Less chance of affecting the product hence better quality. Better retention of sensitive components, flavours, colours Greater throughput per day.

A number of modifications have been developed or suggested by people using dryers in different countries. This, in fact is one of the most interesting aspects of the drying programme. Each country using the dryer takes an initial prototype which is then adapted according to local needs, construction materials, methods of working. Few, if any of the dryers currently in use are identical.

Which route then should an intending user chose? No hard and fast rules can be applied, as much will depend on the crop and local situation. The following points however should be carefully considered:

Are fuel costs a major concern? In some cases the cost of fuel is only a very small percentage of total cost. In such cases time and money might be better spent on better packaging or advertising.

Is the product of very high value? Here over drying would reduce profits as less water is being sold with the product. Quality may also be lower.

Is the product very sensitive to heat? Spices and medicinal plants for example may loose more of the active, sensitive components if batch dried.

Local labour costs and social attitudes. Does shift work involve a very high bonus for example or are workers unlikely to want to work nights?

Most users process a range of products rather than just one type of crop or food. Therefore a semi-continuous dryer is recommended, because it can also be used as a batch dryer and therefore provides the most flexibility. For business purposes, the *DRYIT* dryer provides an ideal starting point. *DRYIT* is medium size and semi continuous, ideal for flexibility and experimentations when starting a drying business.

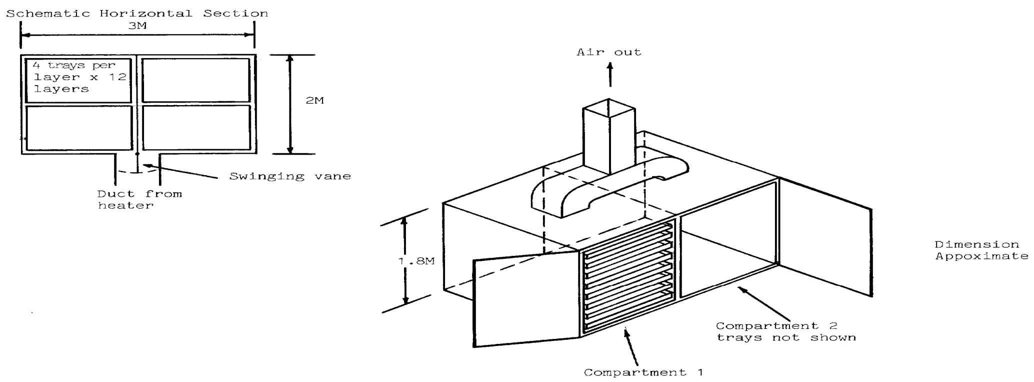

Figure 2: Batch dryer, showing compartments

The *Dryit* range of dryers

Batch dryer

The batch dryer is shown in the diagram above. The drying chamber is divided into two compartments each holding 48 trays 4' x 3' .The trays are arranged so as to force the air to follow a zigzag path. This double chamber is recommended as it allows greater flexibility. If only a small amount is to be dried only one chamber can be used and obviously two different products can be dried at the same time. Air supplied from the heater-blower can be diverted to one or both chambers by means of a simple flap. Most users construct a frame in 3” x 2" timber, which is clad in plywood. The chamber should be supported off the floor to reduce heat losses and preferably insulated.

Cost constructed in the UK approximately £1700 including heater and thermostat

Capacity for herbs: approximately 250kg/day

Heat source: 60kW, 2800 m^3/hr (200,000 BTU, 1650 cfm) heater blower. Such heaters cost approximately £1100. If kerosene fired the heater must be indirect -that is have a heat exchanger so that the gases of combustion are removed by a chimney.

Semi-continuous Tray Dryer

The drying chamber holds up to 16 trays approx 3ft x 4ft. Constructed from angle iron and steel bar and clad with plywood. When used for herbs a typical tray change time is 15 to 20 minutes.

- Cost (UK constructed): £3000
- Capacity: approximately 350 kg/day with herbs
- Heat source as for batch dryer
- Medium semi-continuous tray dryer

This is a recent development and is essentially a half-sized version of the SC above. The main structure is of wood with the minimum of metal parts. The chamber holds up to 12 trays each 90cm x 70cm

- Cost: in UK £1000
- Capacity: approximately 70 kg/day
- Heat source 14-41 kW, 680m^3/hr (48,000 to 140,000 BTU, 400cfm) gas fired blower. Heaters of this size cost approximately £300.

Some economic considerations

It is clearly of crucial importance for any small business to understand how to calculate and analyse its costs in order to:

- Be sure that the business is profitable
- To analyse where cost savings and investment are
- Best introduced
- To carry out rough preliminary costings for a new product line.

This section does not attempt to follow, or replace, the traditional cash flow, internal rate of return types of calculations typically prepared by banks etc. Its aim is to concentrate on some practical aspects that will allow the business to gather raw data for the preparation of a conventional business plan.

The basic aim of any industrial processing operation is to make sure that the value being added per ton of production is greater than the total of all the costs involved in producing and selling it.

In the case of drying the main production cost areas needing consideration are:

- Raw material cost per unit of usable raw material
- The product drying ratio i.e. kg of dry product from 100 kg fresh material
- Fuel costs
- Labour
- Packaging
- Equipment costs and depreciation
- Distribution, marketing etc
- Rent
- Overheads

While a full analysis of all the above is essential to develop a business plan this section will concentrate on the first four areas as they involve crop processing and technical selections that conventional business advisors may not be able to provide.

Raw material cost per unit of usable raw material

No incoming raw material will be totally usable; there is always some wastage through second grade and damaged material and preparation (skinning, stoning, selecting etc) prior to drying. It is recommended that a quantity of raw material is purchased, weighed and then prepared for the dryer.

Wt. Fresh material x cost/kg = cost /kg prepared material
Wt. prepared material

This preparation ration can vary through two main factors. Firstly, the nature and variety of the raw material and, secondly, the quality delivered by the supplier. It may therefore be useful to examine both these aspects.

For example, in the production of dry mango a quantity of 3 varieties were purchased from 3 different suppliers and the following test was carried out.

	% of damaged, low grade fruit rejected		
	Variety 1	Variety 2	Variety 3
Supplier A	10	8	14
Supplier B	8	6	10
Supplier C	13	11	20

This indicates that supplier B is likely to be more reliable and also that variety 3 is more susceptible to damage.

The Selected sound fruit from the above test was then peeled and stoned and the % of usable flesh weighed.

	% of usable flesh		
	Variety 1	Variety 2	Variety 3
Supplier A	40	46	52
Supplier B	42	47	50
Supplier C	39	45	53
	40.3%	46.0%	51.6%

This shows that the usable flesh depends on the variety and not on the supplier.

Knowing the relative prices of the 3 varieties, from the 3 suppliers, will now allow the processor to decide which is the most economic to use.

	Variety 1	Variety 2	Variety 3
Supplier A (price per 100 kg)	$10	$10	$15
Wt usable flesh (kg)	36	42.3	44.7
Cost of usable flesh	27 c / kg	24 c /kg	34 c/kg
Supplier B (price per 100 kg)	$8	$10	$12
Wt usable flesh (kg)	37.1	43.2	46.4
Cost of usable flesh	22 c / kg	23 c /kg	25 c/kg
Supplier C (price per 100 kg)	$10	$8	$14
Wt usable flesh (kg)	35.1	40.9	41.3
Cost of usable flesh	28c / kg	19.5 c /kg	33 c/kg

This example shows that the best choice would be Variety 2 from supplier C which is not perhaps the obvious conclusion from the original raw data and demonstrates how some simple trials can affect profits. If supplier B and variety 3 had been selected (as the best in Table 1 above) prepared pulp would cost $250/ton while the final choice only cost $195. Once again however 'life is not so simple' .It might well be found that one variety after drying had a much better colour or flavour. This again would affect the final choice with questions having to be asked as to whether using this variety would win a market, or put the price up to an uncompetitive level.

Product drying ratio

During the drying process moisture is removed from the food product, so the weight of final dry product is always less than the original weight put into the dryer. The ratio between the final dry weight and initial weight put into the dryer is called the *Drying Ratio* and depends upon the initial moisture and final moisture contents.

Initial moisture content. Ideally this needs to be checked in a laboratory but books are available that give typical levels of a wide range of commodities. In general, moisture levels of fresh produce lie between 75 and 90%.

The final moisture content depends on the product in question. It must be low enough to make sure that micro-organisms such as moulds cannot grow.

Some typical fresh and dry moisture levels are shown below:

	Raw	Dried
Most fruits	c. 85%	15-20%
Herbs	c. 90%	5%
Green leafy vegetables	85-90%	8%
Coconut flesh only	40%	2-3%

The following example shows how to calculate the drying ratio when the fresh and dry moisture levels are known.

A green leafy herb with a fresh moisture content of 90% is to be dried to a final moisture of 6%. What is the drying ratio?

100 kg fresh will contain 90kg of water and 10 kg of totally dry matter.

10 kg of totally dry matter (0% moisture) will increase in weight, if its moisture content rises to 6% by:

$$10 \times 0.06 / 0.94 = 0.64\text{kg}$$

Thus 100 kg of fresh herb will, after drying, yield 10.6 kg of dry product. The drying ratio is thus:

$$100 / 10.6 = 9.4: 1$$

This figure is very useful. If for example 648 kg are fed to the dryer the yield will be:

$$648 / 9.4 = 69 \text{ kg.}$$

It is also useful in calculating when trays of material are dry enough to be removed by:

a) Weighing the empty tray,
b) Adding a known weight of raw material and
c) Checking when the tray reaches a calculated final weight.

In addition this calculation, by using the weight of water removed, has application in determining dryer capacities (see later)

Fuel consumption

The measurement of fuel consumption is fairly simple. If kerosene fired burners are used, the tank should be dipped with a marked pole to determine fuel use. Alternatively if burner specifications are available a graph of fuel consumption at different temperatures can be prepared as shown in the example below:

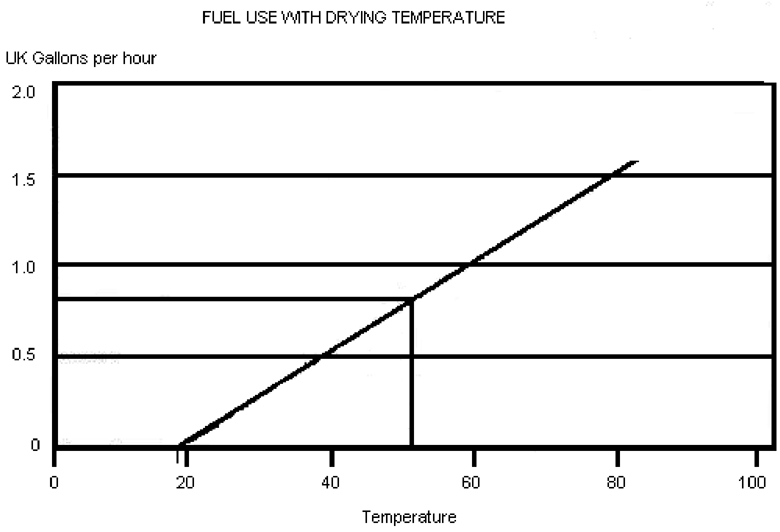

Figure 3: Graph to show fuel use with drying temperature
ID 200 kerosene fired burner. Fuel pump rate 1.6 gall/hr as used in the batch dryer and SC. Max temp lift above ambient 70 °C.

Thus if the ambient temperature is 25ºC the air temperature from the burner will be 95ºC with the heater running full heat (all the time). The consumption will thus be 1.6 gall/hr. If the thermostat is set at 25ºC the burner will not provide any heat, so fuel use will be zero. This can be plotted on a graph and fuel use at any temperature read off with ease.

In the case of propane gas fired burners the simplest way is to weigh the cylinder to measure gas usage. Again a simple graph of fuel use against temperature can be prepared by experimentation.

Labour costs

These are fairly straightforward to calculate. Is worth stressing however that semi-continuous drying does involve 24 hr working. The following points need to be thought about:

Is shift working socially acceptable? What level of shift pay is involved?
The labour cost per kg of final product should be worked out for both batch and semi-continuous bearing in mind that semi-continuous has a greater throughput and uses less fuel
Is a night watchman employed in the plant? Could he work the dryer?
Is the quality better in semi-continuous? Does this actually matter?

Packaging

Packaging can represent a major cost: often due to having to buy it in large amounts, which ties up a considerable amount of capital. Good packaging and presentation however a vital matter for producers. In many cases the pack is the first point of contact with the buyer and the message it gives can lead to a sale.

It is strongly recommended that expert advice is obtained initially on the best technical package to protect the dry food through its shelf life. The design etc should then follow.

The principles of drying of foodstuffs and the tray dryer

This section has been divided into four sub-sections:

- Technology
- Science
- Maths
- Summary

Each sub-section can exist on its own and hence be read either independently of the others or in combination with the other sub-sections depending on what the reader would like to know and when he or she wants to know.

A. Drying as technology

In this section the tray dryer user will be introduced to the four key factors that control the drying process and that can be controlled by the tray dryer user.

Drying involves the removal of water from a raw material to produce a dried food. Dried food is more stable than fresh food. The most common way of drying foodstuffs is to allow the air that surrounds the food to take up this water in the form of water vapour.

People have been drying foodstuffs and other materials for thousands of years. In those early times the principle reason for drying was to conserve the food for use when fresh food supplies were less. The 'tools' then available for drying were the sun, the dry air in certain parts of the world and the heat from a fire. Today of course the conservation of foods by drying, especially cereals and pulses, still plays a very important role and in many parts of the world the traditional practises are still used.

However, today there is a much greater variety of dried foods and a greater variety of tools to do the job. These tools cannot always replace the traditional tools in all situations - mainly for economic reasons - but these tools enable the drying process to be better controlled, which is a very important factor for many dried foods that are of high value and very high quality. The modern tools are also relatively much more expensive than the traditional ones and this can limit the opportunity for uptake by the small business.

What is controllable drying?

Drying is controlled by four main factors:

- The temperature of the air;
- The humidity of the air
- The quantity of the air
- The surface area of the material

One every day example which can be used to illustrate these factors is drying clothes on a line outdoors.

- On what sorts of days do clothes dry best?
- What is the effect of hanging clothes on a line?
- Why are clothes dried outside whenever possible?

Why drying needs to be controlled

Drying needs to be controlled because food is valuable and food is susceptible to spoilage. Slow drying may allow the growth of undesirable micro-organisms, which cause food poisoning or at the very least render the food unsaleable. If the food cannot be sold then money and profit has been lost. However drying too fast can also cause a loss of quality through both physical and chemical changes such as case hardening (see below) and loss of colour, flavour and nutritional value. Hence drying is a balance between obtaining the most highest quality product at the lowest cost to the business.

The four factors

From the four factors it can be seen that three of them relate to the air and one to the food to be dried. We are now going to examine the factor that relates to the food to be dried:

1. The surface area

Drying involves the removal of water from a raw material. The most common way of drying foodstuffs is to allow the air that surrounds the food to take up this water in the form of water vapour. If there is water vapour then there has been evaporation. In drying, the evaporation of water into water vapour occurs at the surface of the material, not inside the material. Therefore the more surface, the more evaporation.

If there is more evaporation then there is more loss of water from the material. In other words the rate of drying is controlled by the surface area.

The composition of foodstuffs affects the movement of water inside the food to the surface. For example sugary and starchy foods can be expected to dry more slowly than open textured or 'low density' foods such as onions and herbs.

In practical terms how can the surface area be increased?

Food preparation techniques such as slicing, dicing and chopping all increase the surface area. Example: The surface area of a 4cmx4cmx4cm cube is (4x4)x6 = $96cm^2$.

If that cube is chopped into 2 equal cubes the surface area becomes:

$((4 \times 4) \times 4) + ((2 \times 4) \times 8) = 128\ cm^2$

Chopping those two cubes each in half gives a surface area of:

$(4 \times 2) \times 16 + (2 \times 2) \times 8 = 192\ cm^2$

Sometimes of course it is not desirable to increase the surface area of a foodstuff prior to drying because of the requirements of the market. An example here is spices such as cloves and cardamoms. The market requires, generally whole cloves and whole cardamoms. Hence the other controllable factors have to be considered to produce a good quality product at a competitive price.

2. The temperature of the air

Drying needs dry (low humidity) air and temperature is, for the purposes of drying, the most common way of reducing the humidity of the air. Dry air has more capacity to take up water vapour from the surface of the food to be dried. Hence drying goes faster with dry air.

The temperatures used in drying (40 - 60°C) cannot really be considered to destroy micro-organisms. For this reason good standards of cleaning and washing foods must be used prior to drying. In fact the warm and humid conditions inside a dryer could be highly suitable to growth of micro-organisms. Hence drying should be carried out as quickly as possible to get a dried product, which will not support the growth of micro-organisms. (For most dried foods between 5 and 10% water). In controllable drying it is possible to consistently achieve maximum drying rates because there is minimum dependence on less controllable factors such as climate.

3. The humidity of the air

The humidity of air is the amount of water carried by it. Humidity can either be measured in absolute terms (kg of water per kg of air) or in relative terms. For example, air at 30%, (of the maximum potential), humidity. The lower the humidity the more useful the air for drying purposes. As mentioned above raising the temperature has the effect of lowering the humidity of air. Passing air of lower humidity over the material to be dried results in a greater rate of drying.

This table shows the effect of heating air at 30°c and 70% RH and ability to pick up moisture

Temperature °C	RH%	Maximum Potential Weight of Water that this air can pick up (kg/kg air)
30	70	0.002
40	40	0.006
50	22	0.009
60	12	0.012

4. The quantity of air

Referring back to the analogy of drying clothes, it is most common for clothes to be dried outdoors. The major reason for this is the good availability of moving air. Drying rates can be increased when relatively large volumes of fast moving air are used. Fast moving air means that a greater quantity of dry air is passing over the material to be dried which means that more water vapour can be picked up by the air and carried away. This in turn means that water within the material will move to the surface at a greater rate.

In most drying systems the quantity (or volume) of air delivered by the fan connected to the heater is not variable. If local construction of a heater unit with fan is considered then one point to be aware of is backpressure. The ability of a fan to work against a backpressure is quoted in fan specifications as inches water gauge "wg. This is the pressure created within the dryer when it is fully loaded with material to be dried. The effect is to restrict the flow of air through the dryer. Consult your engineer that the "wg of the fan is enough. The better design of fan the better it can overcome the effects of backpressure and maintain a high airflow rate through the dryer. Hence always use the best quality fan available. A very high airspeed can always be reduced at low expense using dampers. Fan replacement is more costly.

Case hardening

Case hardening is a phenomenum of drying which affects the quality and is related to a combination of the above factors. It is, as the words suggest, the formation of a hard case around the food pieces. This case or coat prevents further evaporation of water at the surface of the food. Hence drying stops and what results is a tough dry exterior and a soft, moist interior. The interior is therefore susceptible to spoilage and the overall quality of the product is very low.

Case hardening generally affects sugary and starchy foods such as bananas, potatoes and whole fruits. Fruit in slices, herbs and most vegetables are not susceptible to case hardening.

So how does case hardening happen?

During drying, water is evaporating at the surface of the food. Hence the surface of the food is effectively dryer than the inside of the food. This is an imbalance which nature will attempt to correct by causing water inside the food to move towards the surface. In some foods however, the water which moves to the surface carries with it a very large amount of other components such as sugars, starches, and minerals. When the water evaporates these components will be left on the surface of the food. They gradually build up and form a barrier through which water cannot pass. When no more water is reaching the surface, the surface dries out, becomes hard and further drying stops.

In those foodstuffs that are susceptible to case hardening the greater the rate of movement of water to the surface the greater the chance of case hardening. It can be seen then that case hardening is dependant on the type of food to be dried and rate of drying. The simplest ways to make drying proceed more slowly are to use a lower drying temperature or reduce the surface area. But the surface area should be large for those foodstuffs which easily become case hardened because a large surface will mean that the sugars, starches etc which move to the surface will be distributed more thinly across a greater area. Hence the most effective way to reduce the rate of drying is to lower the drying temperature. For foodstuffs that are susceptible to case hardening temperatures the humidity of the air used for drying should not be too low. The temperature will control this.

Summary

The objective is the most dried product of the highest quality in the shortest drying time at the highest quality.

The four controllable factors in drying are:

-temperature -humidity - quantity of air - surface area

The higher the temperature, the lower the humidity and hence the greater the capacity of the air to pick up moisture from the material to be dried. Air is made even more useful by increasing the volume that passes through the drying chamber. Increasing the surface area of the material will also increase the rate of drying.

Care is needed to avoid case hardening in some foodstuffs. Normally the airspeed can be decreased although not increased.

With a careful balance of these four factors the quality of the product will be high ie no case hardening, no potential problems of spoilage, no serious losses of colour and flavour and production costs will be lower.

Maximising efficiency

The most efficient drying system is one in which the air which is exiting from the dryer is as 'useless' as possible. In other words it has little or no capacity to absorb more water vapour. The first step though in getting close to this situation is to load the dryer with as much material as possible. Here care needs to be taken to ensure that the air can pass over all the surfaces of the material. With herbaceous materials this is not too difficult to achieve. However with sliced materials: apples, potatoes etc only one layer should be on each tray. Here a large number of very shallow trays would be required.

Having ensured that the maximum amount of material is on each tray then the temperature should be adjusted up to the point where the amount of humidity in the exiting air is starting to decrease.

Other factors which control efficiency are the efficient use of heat used for drying and the efficient use of labour.

At the end of the day the key questions for the tray dryer user are how many kilos have been produced today for how many gallons of diesel or kilos of gas and what the quality is like

Equipment

Based on the controlling factors some equipment would be necessary if one were to start researching the optimum drying conditions for different foodstuffs. Practical Action and many other organisations have already done a lot of work in this area and are in a position to provide the drying temperatures, drying times and potential drying capacities for many herbs, fruits and other foodstuffs. This data will give a good indication of drying conditions. However, some adjustments may be necessary due to variations in humidity in different places and at different times of the year.

It would be useful to have (or access to) some scientific equipment to make a number of measurements especially for the early stages of investigation. Such equipment would not need to be used all the time once the operating conditions have been established.

The most useful scientific instruments are:

Humidity meter
Thermometer
Anemometer

Drying as science

In this section the four key factors are discussed in relation to the scientific principles of drying.

Why does drying help to conserve foods?

All forms of life need water in one form or another. Micro-organisms are no different and in food processing a crucially important objective is to ensure that micro-organisms cannot spoil food. Therefore reducing the availability of water will reduce the opportunity for the growth of micro-organisms.

Drying is one way of reducing the availability of water. The key phrase is the availability of water not dryness. There are many foods, which are not exactly dry but have a low availability of water for micro-organisms. For example dried figs are not dry in the conventional sense. They contain about 25% water yet they last a very long time without spoiling. On the other hand any cereal with that much water would soon spoil.

The difference is in the way in which water in contained within the food and the composition of the food. In dried dates the sugar helps to contain the water yet in a way that makes it unavailable for micro-organisms. In cereals only very small quantities of water can be contained in this way. Hence when this level is exceeded the remaining water can support the growth of micro-organisms. The moisture level in a food at or above which micro-organisms can grow is sometimes called the critical moisture content. Therefore in dates the critical moisture content is about 25%. In cereals the critical moisture content is about 12%.

The implications of this difference are in packaging and storage requirements. All foods will come to equilibrium with their environment. For example very dry foods will absorb water in a humid climate until the system is balanced and no more can either be absorbed by the food. Or likewise the air will absorb water from a moist food in a dry climate. This phenomenon is similar to the movement of water to the surface of a food during drying.

The key factor is whether the moisture content at equilibrium with the environment is greater than the critical moisture content of the food. Drying will, in most cases, lower the moisture content of the food to below the critical moisture content. However once dried the food must be stored and packed under conditions which maintain the moisture content below the critical moisture content and this depends on the environment. For example in a very humid climate, foods with low critical moisture contents such as dried herbs need to be packaged in materials which have very good water vapour resistant properties such as polypropylene.

The rate of drying

Another important concept in drying is the rate of drying. Earlier we talked about the rate of evaporation and the movement of water from inside the food to the surface where it gets picked up by the moving air as water vapour. Two basic rates of drying are observed during the drying process:

- Constant drying rate
- Falling drying rate

Constant drying rate (figure 4)

This takes place in the early stages of drying. At this stage there is a high availability of water on and very near to the surface and hence it can move easily and quickly to the surface where it evaporates. More water then moves to the surface. During the early stages it can therefore be assumed that the surface is constantly wet due to the constant relatively large volumes of water that are moving to the surface. The rate of evaporation is therefore constant. And therefore the rate of drying is also constant. See points B - C on the drying curves.

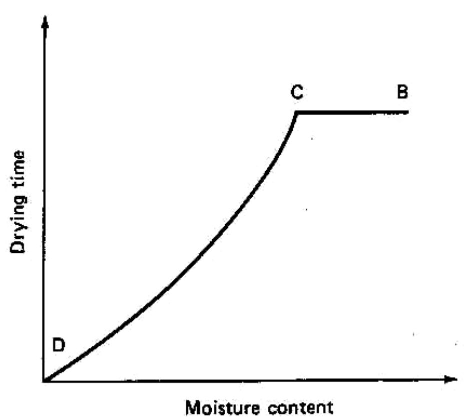

Figure 4: typical drying curve

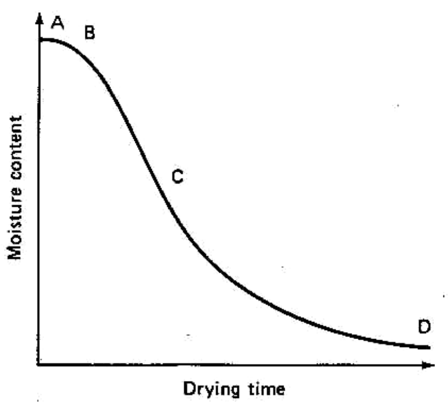

Figure 5: typical drying rate curve

Falling drying rate (Figure 5)

As the food dries the movement of water to the surface for evaporation decreases. This is because there is less water and components such as sugars and starches, which release water only very slowly, are having a more significant effect on the overall drying rate. See points C - D on the drying curves.

Implications

During the constant rate period the key factor is the rate of evaporation at the surface of the food. This can be maximised by decreasing the humidity (through raising the temperature) and ensuring a good quantity of air is being supplied. The water in the food can be picked up easily from the surface and so the rate of movement of water to the surface is high. However fast drying rates are not required for case hardening susceptible foodstuffs.

During the falling rate period it is the rate of movement of water to the surface which becomes increasingly more significant than the rate of evaporation. This rate of movement is dependant on the temperature and the surface area. The greater the temperature the greater the rate of movement of water to the surface; the greater the surface area the easier it is for water to reach the surface ie the less it has to travel.

In the case of the tray dryer

In the semi-continuous tray dryer the raw material starts in an environment of fairly warm moving air. The humidity is actually quite high at the top of the dryer and there may not be much drying in the top tray. As trays from the bottom are removed and new trays loaded at the top, the trays gradually move through zones of dryer and warmer moving air until eventually the raw material is in a zone of low humidity and high temperature. Case hardening is minimised with this system because drying rates are quite low in the early stages.

Psychrometry and the psychrometric chart

Psychrometry is the study of the properties of air. In other words what is going on when air is heated up or cooled down. The diagram below is a typical representation of the psychrometric chart.

It looks complicated but....

What is so useful about this chart is that it enables one to predict for example, how much water vapour can be removed from a raw material using a particular condition (temperature, humidity and quantity) of heated air. For example from psychrometry it would be possible to measure if, in a dry warm part of the world, it was actually worthwhile, in terms of cost and throughput, to heat the incoming air. It may be just as effective to use ambient air at high speed. Possibly raising the temperature towards the end of the drying process.

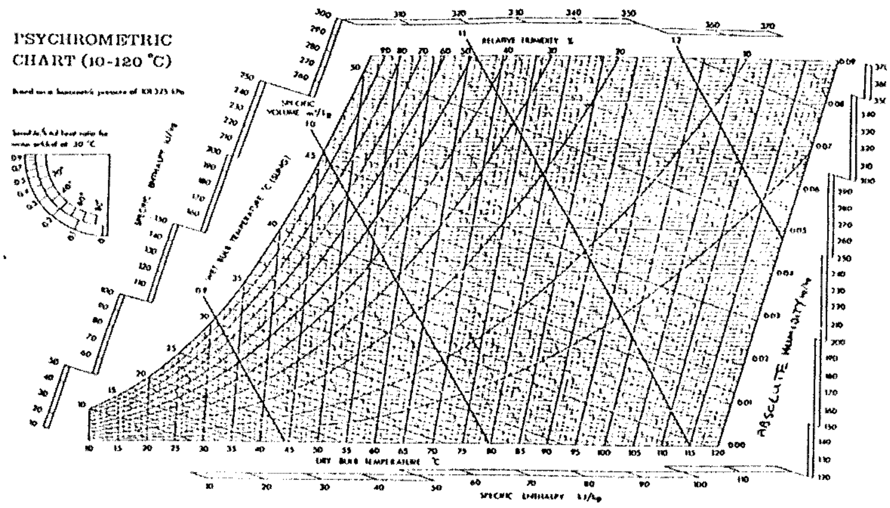

Figure 6: Graph to show temperature of bulb against humidity

The psychrometric chart explained

Dry bulb temperature

One axis gives the dry bulb temperature. This is the temperature of air using a standard thermometer.

Absolute humidity of air

The other axis gives the absolute humidity of air which is the weight (kg) of water vapour in 1kg of dry air.

Percentage saturation lines

The percentage saturation lines relate to the absolute humidity of the air as a percentage of the absolute humidity of air that is fully saturated (when the air can hold no more water vapour). This is very similar to relative humidity and hence relative humidity values are more commonly used. For example air in a tropical basin region of the world, such as the Amazon, at 85% relative humidity (RH) is relatively more humid than air in a tropical mountainous region, such as the Andes, at 25% RH.

Adiabatic cooling lines

The adiabatic cooling lines show what happens to the temperature and humidity of air when it is used for drying. The heat in the air will be used to evaporate the water. This will cause the air to cool down which in turn will cause it to lose capacity to pick up water vapour. ie the air effectively becomes more humid. On the psychromatic chart the adiabatic cooling lines go 'up' the absolute humidity axis as one goes 'down' the dry bulb temperature axis from right to left.

Wet bulb temperature

A wet bulb thermometer is a standard thermometer with the mercury bulb enclosed in a cotton sock which is soaked in water. This has the effect of creating an atmospheric condition of air that is at 100% RH ie is fully saturated. Hence the wet bulb temperature line indicates the temperature of saturated air. These temperatures are given on the psychrometric chart because in a perfect drying situation the air coming out of a dryer should be at 100% RH.

When a wet bulb thermometer is placed in the same air as a dry bulb thermometer the wet bulb temperature is always less than the dry bulb temperature, (except when the dry bulb is in air that is 100% saturated), because evaporation from the water soaked cotton sock surrounding the thermometer bulb has taken place in order to balance the humidity with the surrounding air. Evaporation causes cooling because the energy for evaporation has come from the heat in the air. Hence the air will cool down and will hold less water vapour. So the air gradually cools until it reaches a temperature where it can absorb no more water vapour from the cotton sock ie it too has reached saturation. At saturation there is no evaporation. This is the wet bulb temperature.

The best-known use of these two types of thermometer is for recording the weather. So, for example, on a very hot dry day there would be a lot of evaporation from the sock and therefore a lot of cooling of the temperature. The greater the difference in temperature between the wet and dry bulbs the lower the humidity of the air. Tables are available which give the humidity of the air from knowing the wet bulb and dry bulb temperatures.

Pickup factor

The psychrometric chart is a theoretical tool for measuring the potential of heated air to pick up moisture from a material such as food.

In reality the data obtained from the chart hardly ever matches the data obtained from practical experiments. Hence a 'pick-up factor' is used to convert the data from the psychrometric chart into more realistic data. Although it is unlikely to be exactly the same as data from practical experiments it would be much closer.

The pick-up factor ranges from 10-50% of the theoretical figure.

Why is it so low?

The ability of air to pick up moisture depends on a number of factors such as how easily the moisture is evaporating from the food to be dried and how well the air mixes with the food. During the initial stages of drying, moisture is evaporating easily from the surface - the constant rate period. However during the falling rate period the moisture is evaporating less easily. Hence the pick-up ability during the falling rate period is lower than during the constant rate period.

Normally the constant rate period is much shorter than falling rate period. This means that in drying of foodstuffs the average ability of the air to pick-up moisture is going to be low. The greater the initial moisture content, the longer the constant rate period. Similarly the lower the desired final moisture content, the longer the falling rate period.

Not only are the initial and final moisture contents important in determining the pick-up factor but also the way a particular food dries and the design of the dryer affects the pick-up ability.

How to select a pick-up factor

Generally it can be said that foods that dry easily and quickly such as herbs and some vegetables will have a higher pick-up factor (50%) than fruits, starchy foods and semi crystallised fruits (30-10%).

Drying efficiency

The efficiency of drying is an overall measure of how much of the energy supplied to the Dryer is used to dry the food. It is a different indicator than the pick-up factor. The efficiency of a Dryer is calculated without using a psychrometric chart because it is based on factors such as weight of water lost during drying and the amount of heat supplied to the Dryer. These can be worked out without referring to the chart. A very efficient dryer uses ALL of the energy supplied to dry the food. A very inefficient dryer dries food more slowly because, for example, heat is lost from the dryer and air comes out from the dryer still with capacity to remove water.

Efficiency can be improved by making modifications to the insulation of the Dryer, use of re-circulated air, by ensuring that as much as the raw material as possible comes into contact with the air without overloading and by ensuring that the exiting air is as saturated with water vapour as possible.

Drying as mathematics

In this section the knowledge gained from the previous two sections will be applied to enable predictions of the drying process to be made.

I. The Psychrometric chart can be used to calculate:

a) the potential of air to pick up moisture from a raw material

b) the potential amount of water that can be picked up over time

The following basic data will be needed:

- Temperature of air entering Dryer
- Temperature of surrounding air
- Humidity of surrounding air

II. The efficiency of the drying process can be calculated from knowing how much water was actually removed from the raw material and how much heat (or energy) was used to assist that process.

What is the potential of the heated air to pick up moisture from the material?

Working through the following example:

Surrounding air: Temperature 18°C
RH 60%

The Dryer heats the air to 50 °C

From the psychrometric chart

A dry bulb temperature of 18°C and 60% RH corresponds to point A. Reading across to the absolute axis (point B) gives a figure of:

0.007kg moisture/kg air.

It is then possible to calculate the maximum possible amount of water vapour in the air at that temperature.

From point A follow an adiabatic cooling line to the 100% saturation line. This is point C. It tells you that the equivalent wet bulb temperature is approximately 13°C. (see figure 7)

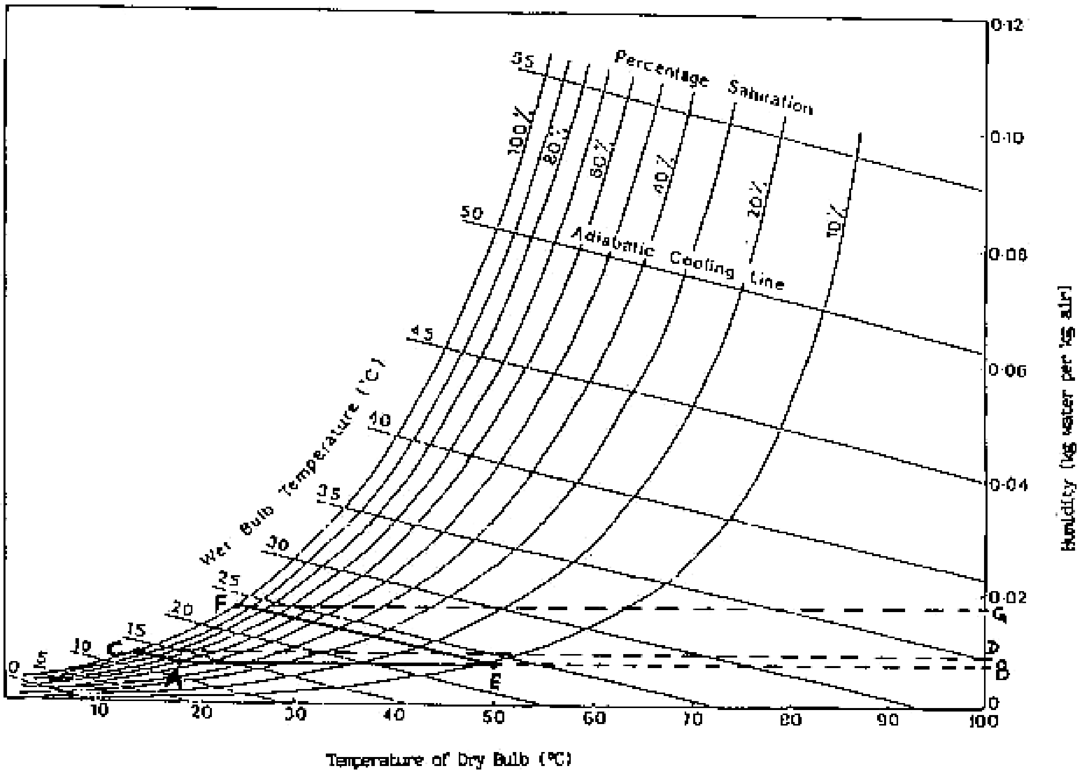

Figure 7: Graph to show temperature of dry bulb against humidity

Read across to the absolute humidity axis (Point D):

0.009kg moisture/kg air

Point D - Point B = Potential of the ambient air to pick up moisture.

0.009 - 0.007 = 0.002kg moisture per kg air

After heating the air to 50°C.

From point A take a line horizontally across to the 50°C point. This is Point E.

Follow adiabatic cooling line to 100% saturation (Point F).

Read off absolute humidity from right hand axis (Point G): 0.017kg/kg. Subtract the ambient dry air humidity (point B) from this figure to give the potential ability of the heated air to pick up water vapour.

0.017-0.007 = 0.01kg/kg i.e. 5 times greater than the ambient air potential.

Assume a pick-up factor of 50% for herbaceous materials. This gives a potential moisture pick up of: 0.005kg/kg

From knowledge of the quantity of air passed it then becomes possible to calculate the theoretical drying times for this particular drying condition. (See next box).

To calculate how much water can be removed over time

Using the large tray Dryer and diesel fired heater: The heater has a fan which moves 2800m^3 air per hour: To convert this to a weight of air it is necessary to know the density of the ambient air. This can be calculated from the psychrometric chart:

The surrounding air has a temperature of 18°C and an RH of 60%. On the chart below this corresponds to the value at Point H: 0.84 = specific volume (m3/kg) Therefore weight of air per hour moving through the Dryer:

$$\text{Weight} = \frac{\text{Volume}}{\text{Specific Volume}} = \frac{2800}{0.84}$$

= 3333kg air per hour

From the above box, the heated air can pick up 0.005kg moisture per kg of air.
Therefore air can remove: = 3333kg/hr x 0.005kg/kg
= 16.66kg moisture per hour
= Rate of moisture loss

technical guide

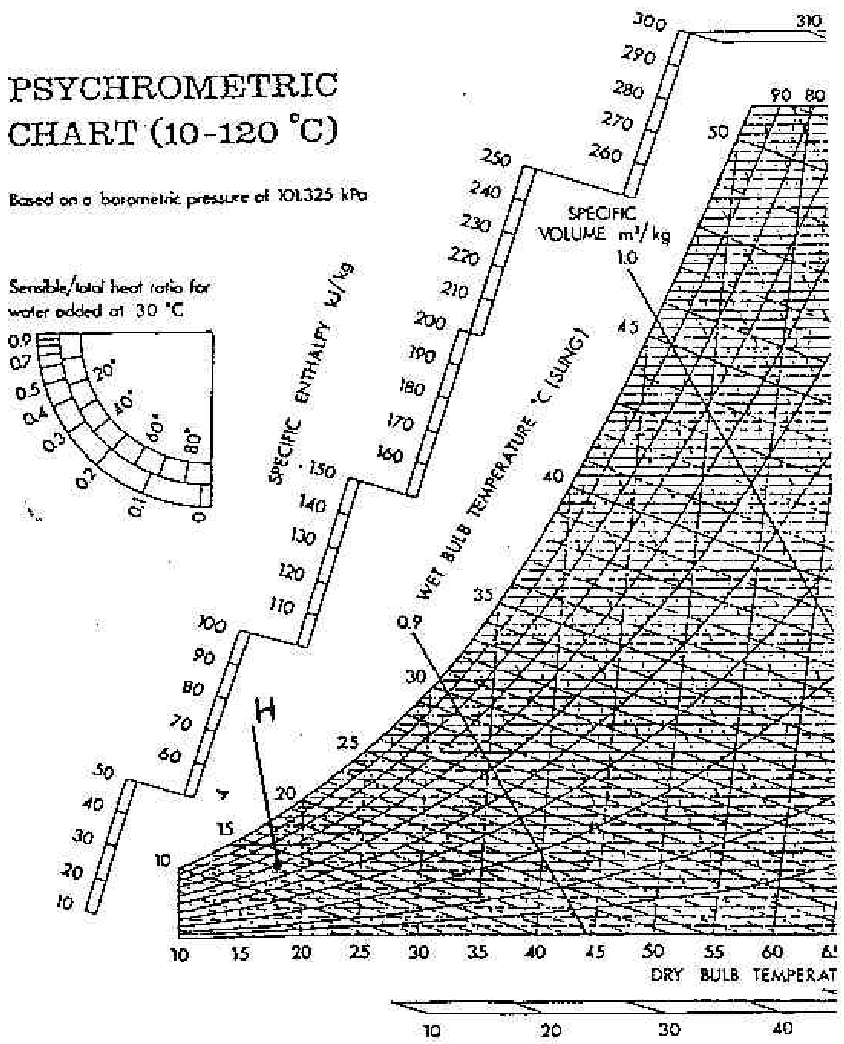

Figure 8: Section of a psychrometric chart to show specific volume of surrounding air

- Tray loading: = 75kg of material
- Initial Moisture content: = 90%
- Desired final moisture content: = 6%
- Total moisture in fresh material = 75 x 0.9 = 67.5 kg
- Total weight of bone dry material= 75 - 67.5 = 7.5 kg
- Moisture in dried product: = 7.5 x 0.06 / 0.94 = 0.5kg
- Moisture to be lost from material = 67.5 - 0.5 = 67kg

To calculate drying time

= Total moisture to be lost / Rate of moisture loss

= 67 / 16.66 = 4.02 hours

Drying time 4.02hours = 4hrs 1min

Hence after 4 hours it should be possible to dry 75kg of herbs to a moisture of 6% assuming a pick-up factor of 50%.

The efficiency of the dryer

By actually knowing how much water was removed in a given time at a given temperature using a given fuel it is then possible to calculate the efficiency of the drying system.

Thermal Efficiency = kg water evaporated x latent heat / kg fuel used x heating value of fuel

= (Energy actually used / Energy put in to the system) x 100%

How much fuel is used

Using the diesel fired heater it is known that the fuel consumption is 1.6 gallons per hour. As mentioned earlier, the heater is rarely 'on' all the time. Hence the average fuel consumption is less than 1.6 gals/hr. From the graph drawn below it can be seen that at 50°C, the average fuel consumption is at point I (see annex for more details):

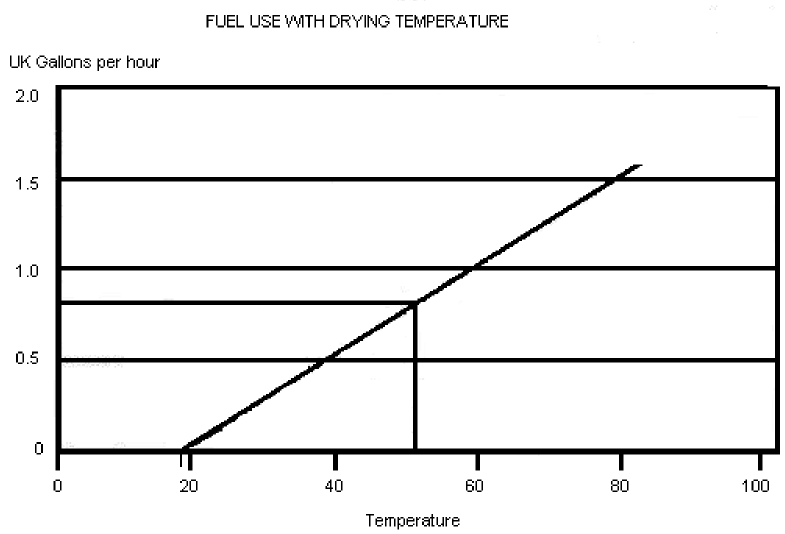

Figure 9: Fuel use with drying temperature

Point I = 0.7gals/hr = 0.7 x 4546 cm3 / hr

(4546 is the conversion factor from gals/hr to cm3/hr)

= 3182 cm3 / hr

The density of diesel is: 0.82 g / cm3. Therefore the weight of fuel used per hour is

= 3182 x 0.82 / 1000

= 2.61 kg/hr

To calculate drying efficiency from example drying data

Assume 65kg of product went into the Dryer at 95% moisture. After 41/2 hours the product was dried to 6% moisture. Hence to calculate total moisture lost:

= 65x0.95 = 61.75kg moisture

= 65-61.75 = 3.25 dry material

With 6% moisture this weighs = (3.25 x 0.06 / 0.94) + 3.25 = 3.46 kg

Total moisture lost = 65 - 3.5 = 61.5 kg

Thermal Efficiency = (61.5 x 2.3 / 4.5 x 2.6 x 46) x 100 = 26%

46 is the heating value of diesel (MJ/kg)
2.3 is the latent heat of water at 50°C
2.6 is kg/hr diesel.

A list of useful data is given in annex 1.

Summary of this entire section

The objective in drying is the most amount of dried product at the highest quality and lowest cost. There are four basic factors that control drying: temperature, humidity, airspeed and surface area. During drying there are two basic drying rates: constant rate and falling rate. The above four factors play different roles during each rate.

Drying should take the moisture content of the food below its critical moisture content. Packaging and storage will help to ensure that the critical moisture content is not exceeded in an unreasonably short time. Exceeding the critical moisture will increase the risk of the food spoiling and therefore becoming unsaleable. Different foods have different critical moisture levels and this is reflected in different requirements for packaging and storage.

Psychrometry is the study of the properties of air. Knowledge of how to use the psychrometric is very useful for predicting drying times for a particular drying condition. This is however a theoretical calculation and in practise the potential of the air to pick up moisture during drying is 30- 50% of the values determined from the psychrometric chart.

Thermal efficiency is the measure of how much heat or energy put into the system was actually used to dry the food. Factors that govern efficiency of drying: design of Dryer, batch or semi continuous, condition of exit air, insulation. Additional equipment needed: Anemometer, thermometer, humidity meter.

Operation of the tray dryer

The flow charts detailed below gives the main steps in processing a range of foodstuffs using the tray dryer:

Raw material pre-processing stages

1. Raw material

2. Weigh

3. Remove roots\ stalks\ poor material

4. Wash \ clean raw material

5. Peel \ chop \ slice \ dice

6. Weigh & calculate percentage loss

7A. Storage in brine (if necessary)

7B. Peeling (if necessary)

7C. Osmo-soak (if necessary)

7D. Blanch (if necessary)

7E. Use of sulphur dioxide (if necessary)

8. Load onto trays

Operation of semi-continuous tray Dryer

9. Switch on heater unit

10. Check thermostat operation

11. Set at desired temperature

12. Load trays into Dryer

13. Drying starts

14. Removal of bottom tray

15. Load fresh tray

16. After pre-determined time Removal of subsequent trays

17. Load fresh tray each time one tray is removed.

18. Packaging

Notes on pre-processing stages

1. The raw material can be any fruit vegetable or herb. Processing of meat and fish will not be considered in this manual. At this stage the raw material is probably in an unwashed and unprocessed state.

2. The first operation is to weigh the raw material in the condition that it was purchased.

3. After weighing, if it is necessary, the excess roots or stalks or second grade material should be removed. This may particularly apply to herbaceous materials and some types of vegetables. It is important at this stage not to remove too much or greatly expose the inside of the raw material. The objective is primarily to trim away those parts which may be heavily contaminated with earth. This will save on washing water.

4. The raw material should then be washed to remove any dirt or other impurities which should not be carried along the processing operation line. Washing should be done using clean water. Ideally continuous running water to carry away the earth should be used. Otherwise the water should be changed two or three times depending on how much dirt is present.

In the case of herbaceous materials it is recommended that the final wash or soak occurs in water that contains a chlorine based bleach to reduce the contamination by microorganisms. One method is to prepare a washing solution containing 2 tablespoons of normal chlorine bleach per gallon of clean water and let the herbs soak for 10 - 15 minutes. There is no need to rinse because the subsequent stages will ensure that the chlorine is not present in the final product.

5. Once washed and cleaned the raw material can be peeled or chopped or sliced or diced depending on the material and what the final form should be. See section on surface area above.

All the tools should be thoroughly cleaned before use to avoid cross contamination ie there is no point in virtually sterilising the raw material if dirty knives will then be used to cut up the raw materials.

6. The raw material can now be weighed to give the amount that will be dried. At this point the percentage of purchased raw material that cannot be used for processing can be calculated. A loss of 20%, for example, implies that the value of the raw material has increased by a factor of 1.20 per kg. Once an established production line has been set up this step is less important because average raw material loss data will have been built up and can be used.

7. Some fruits and vegetables are particularly susceptible to turning brown when the flesh has been sliced\chopped etc and exposed to the air. To minimise this the cut pieces can be stored in water.

8. The following three stages will very much depend on the type of raw material that is being processed.

Blanching inactivates components in the foodstuffs called enzymes that may cause loss of colour in, for example green vegetables, or browning in, for example, apples. Blanching also has the effect of making the movement of water through the raw material to the surface easier during the drying process. This results in both faster drying and an improved quality when the dried food is rehydrated.

Blanching also has the effect of reducing the contamination by micro-organisms. However this situation can easily change if the raw material is then exposed to unhygienic practises after blanching. For example dirty tables or other pieces of equipment which may come into contact with the raw material.

Blanching is generally recommended for roots and tubers and vegetables. Blanching is usually not carried out for fruits and very rarely for herbs and spices.

Blanching methods

Blanching methods involve dipping the raw material in boiling water for about 3-5 minutes. However there are a number of factors which affect the time of blanching such as the size of the pieces to be blanched, the amount of raw material blanched at anyone time and the temperature of the water.

The easiest way to dip the raw material in the boiling water is to use a cloth bag or sieve. After blanching, the raw material should be dipped immediately into cold water to prevent over-blanching or cooking. This cooling step will assist in maintaining good colour of, for example, green vegetables. However there is a greater loss of nutrients. Cooling in air (preferably cool and moving) is better for retaining vitamins and nutrients.

Blanching can actually help to ensure that, for example, the green colour in vegetables remains as strong as possible during drying and during storage. This is done by adding 1 percent of sodium bicarbonate to the water ie 10 grams per litre of water. However use of sodium bicarbonate will accelerate the loss of vitamin C by about a factor of five.

Blanching by immersion is very straightforward but can cause some nutrients and colours to leach out from the raw material. This can be overcome by blanching in steam for approximately 10-15 minutes. The choice of blanching methods depends on the final quality of the product that is required, cost and availability of equipment.

After blanching the raw material can either go on to a sulphur dioxide step or directly to the Dryer.

Use of sulphur dioxide as a preservative

Sulphur Dioxide (SO_2) is used to prevent growth of yeasts and moulds and to prevent fruits and vegetables from becoming brown during storage. Nearly all fruits are susceptible to browning and hence this step is recommended. As a general guide foods that are preserved by sulphur dioxide are not blanched.

There are two basic ways of adding SO_2: one is by immersion in a sulphite solution (sulphiting); the other is to burn sulphur and allow the fumes to penetrate the raw material (sulphuring).

Sulphiting is more commonly used for vegetables whereas sulphuring is more commonly used for fruits.

Sulphuring has the advantage of not getting the raw material any wetter than what it is already and also gives a more even distribution of the sulphur dioxide preservative. Furthermore it is often the case that rock sulphur (burnt to give fumes of sulphur dioxide) is more widely available than sodium metabisulphite.

Too much sulphur dioxide will give the food a very strong, offensive flavour and if this can be detected by you or the consumer then the legal limit has probably been exceeded.

Method of sulphuring

A sulphuring cabinet needs to be built. See diagram. Approximately 5g of rock sulphur (1 level teaspoon) should be used for each kg of raw material to be sulphured. The correct quantity of sulphur should be placed on a shallow ceramic container and then ignited. The sulphuring procedure should be allowed to proceed for about 2 - 3 hours.

The fumes from burning sulphur are dangerous. They should not be inhaled. After sulphuring the product should be immediately dried.

Method of sulphiting

Sodium metabisulphite is a powder and a highly concentrated source of sulphur dioxide, which is the actual preserving substance. Therefore only very small quantities of this powder are needed. Sulphur dioxide is toxic so care must be taken when using sodium metabisulphite.

Add no more than a ½-teaspoon of sodium metabisulphite to each two litres of water. This gives a concentration of 0.1% sulphur dioxide.

The prepared raw material is then dipped in this solution for 1 minute only.

All raw materials dipped in a sulphite solution should be then immediately dried.

Peeling

In drying this process is used mainly for plums and grapes, which have waxy skins. A weak solution of caustic soda (sodium hydroxide) causes the skins to crack, which helps drying proceed more quickly.

After washing the fruit it is then dipped in a boiling solution of 0.3% (ie 3 g per litre of water) sodium hydroxide for about 3 - 4 seconds. The fruit is then thoroughly washed in cold water to rinse off the caustic solution and to avoid cooking the fruit.

After this process the fruit should be dried.

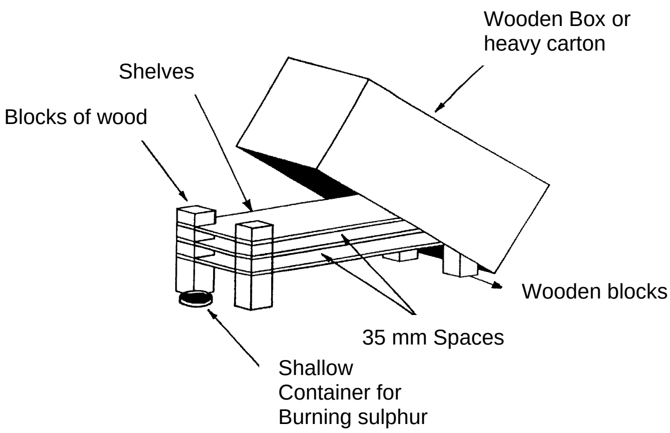

Figure 10: Traditional sulphuring

Osmo-soaking

This is a process, which is particularly used for fruits. Osmosis is the removal of water based on the principle of two different concentrations of liquids coming into balance. Hence by submerging fruit in a concentrated solution of sugar, water within the fruit will move from the fruit to the stronger concentration in an attempt to dilute it.

This is a very useful process because this has the effect of dehydrating the fruit and furthermore, because a quantity of the sugar in the concentrated solution penetrates into the fruit during osmosis, the concentration of sugar in the fruit increases. This sugar will bind with some of the water that remains within the fruit which means that it will not be available for micro-organisms to use. Therefore drying does not have to remove so much water. See notes in section above.

After osmo-soaking and drying the end product will be fairly moist, sweet and will probably be coated with a dry, whitish layer of sugar. Sometimes the fruit flavour is not as strong because some of the flavours may have leached out with the water into the sugar syrup.

If the end product is required to have simply a sweet coating then it is sufficient to only dust the raw material with powdered sugar before air drying. The choice depends on what the consumer wants.

Method to osmo-soak

There are a number of ways to do this. One of the least complicated methods is to add the prepared fruit pieces to a hot solution of sugar at 40% ie 400g of sugar added to each 600ml of water. The fruit is then left to soak in this solution overnight.

This technique does help to minimise the chance of browning because it acts in a similar way to blanching. However it is generally recommended to add ½ teaspoon (max) of sodium matabisulphite to each four litres of sugar solution to give 0.05% SO_2. If sodium metabisulphite is not available then burning sulphur can be used for 1 - 2 hours. See above information on sulphuring.

After the overnight soak the fruit pieces should then be rinsed in clean water and then drained. This removes the excess sugar from the surface of the fruit. After this the fruit pieces should be immediately put into the dryer.

Using the tray dryer

Having done all the preparatory stages the raw material is ready to be dried.

Loading the trays

The key point here is to ensure that the maximum amount of raw material is loaded onto each tray BUT that the air is able to circulate freely around each piece.

Hence in the case of more dense pieces such as sliced potato or fruits only one layer should be on each tray. This makes the depth of each tray very shallow. Hence the design of the tray should reflect this so that as many trays as possible can be loaded into the Dryer.

Leafy and especially herbaceous materials can be loaded more deeply on the trays. Hence ideally deeper trays should be used.

With the medium sized Dryer it is possible to load about 20 kg of fresh herbaceous material. With the same depth of trays, about 10kg of sliced apples one layer thick.

The heater and thermostat

Two types of heater are currently available: gas fired and diesel fired.

The gas fired heater is a direct heater ie the heat from burning the gas is transferred directly to the drying cabinet. A supply of propane gas is required.

The diesel fired heater is slightly more complicated because more regular attention and maintenance is required. The diesel fired heater is an indirect heater ie the heat of combustion is transferred to the air by a heat exchanger as opposed to directly blowing the combustion fumes into the Dryer. Unlike gas, diesel does not burn cleanly.

The most important aspect of the heater is the thermostat. This is an essential item of equipment. It is normally fitted at the base of the Dryer so that it can control the temperature of the incoming air from the heater. The thermostat must be checked regularly and set to the desired drying temperature. The thermostat should be accurate to within plus or minus 3 ºC.

The two other important aspects are the heat output and the delivery of air by the fan. For the large tray Dryer the heater should have a heat output of 200,000 Btu/hr (60kW) and a fan capable of delivering 1600 cubic feet per minute (cfm) or 2800m^3/hr. The heat output gives an indication of the ability of the heater to raise the temperature of incoming air.

For the medium size tray Dryer, heat output should be 50,000 Btu/hr (15kW) with a fan delivery of 400 cfm (680m^3/hr).

Engineering workshops in Peru are now building their own heater units for the large tray dryer. This is an important step forward in terms of increasing self-reliance.

It may be possible to find suitable heaters and thermostats in your own country. However if you are having difficulty with this then please contact Practical Action that will be able to assist with finding suppliers.

Drying

With the tray Dryer the bottom trays will dry faster than the top trays because they are closer to the hot air. As the air moves up over each tray in a zig-zag fashion it becomes more humid and cooler. The air exiting from the Dryer should have very little capacity to dry (see earlier notes).

The drying time of the product can be estimated from the psychrometric chart. The pick-up factor is critical. For less dense raw materials such as herbs it could be 50% of the theoretical value. With dense or sugary or starchy foods such as osmo-dried fruits or potatoes it could vary from 10 - 30% of the theoretical value. The psychrometric gives an idea of drying characteristics. Practical tests will give the true characteristics.

Hence the bottom one or two trays will take this estimated, or hopefully determined, time to dry. In the case of herbs this could be around 3 - 4 hours and for fruit around 8 - 10 hours. After this time the bottom tray should be removed. It should be checked for dryness before complete removal.

Checking for dryness

This depends very much on the type of raw material being dried. Most fruits are dried until they become pliable, leathery and the inside does not appear over moist. Most vegetables and bananas should be dried until they become brittle. Fruits treated by osmosis will be pliable when dry and still appear moist.

This is a very rough guide. More information could be gathered from purchasing samples of a reputable competitor (if applicable). Storage trials are a good indicator of moisture content as earlier discussed.

Removing and loading the trays

The trays are raised by pulling down on the handle and if one person is operating, held in place by the catch. The door is then opened. It will be seen that all the trays except the bottom one have been raised. Then using the hook, never your fingers, the bottom tray can be checked. If the product has reached the desired dryness the tray can be removed.

The door is then closed and the handle slowly released to let the stack of trays drop down. A tray of fresh material can then be loaded at the top. The bottom tray should be checked for dryness. Remove as detailed as above.

If dry then remove as detailed as above

Tray removal interval

Subsequent trays should then be removed at regular intervals. The approximate time of this interval can be calculated thus:

= Time to dry material on bottom tray (minutes) / Number of trays in dryer

For example: 180 / 15 = 12 minutes

In reality the interval should be less because material starts to dry almost as soon as it is loaded into the Dryer.

Each time a tray is removed from the bottom of the stack a tray of fresh material should be loaded at the top.

It is possible to continually unload and load the Dryer provided the amount of prepared raw material is available.

To calculate potential total amount of raw material that can be dried in 8 hours

Tray change time = 12 minutes
Kg per Tray = 3kg
Initial change time = 3 hours

Hence, after 3 hours, 3 kg processed. After 3hrs 12 mins, 6kg processed etc. Start drying at 9am, after preparing raw material since 7.30am At 12 pm 3kg. Every hour = (60/12)x3 = 15kg

Finish drying at 4pm. Therefore total fresh material processed per day = 3 + (15x4)
= 63 kg per day

Working for 24 hours = approx (60 / 12) x 3 x 24 = 360 kg per 24 hours.

Additional notes to be considered by the business

The semi-continuous dryer requires a higher labour input than the batch dryer due to the need to remove trays frequently. (See introduction). Additional labour will also be required to ensure a continuous supply of prepared material for the dryer.

These costs need to be offset against the higher quality product with the semi-continuous Dryer and greater drying efficiencies.

Packaging

After drying, as described earlier in this manual, the dried material will need to be packaged in a suitable material, which keeps the product below its critical moisture for a long period of time. The type of packaging in terms of its ability to protect the product against spoilage will depend on whether the critical moisture level is high or low and the local climate. For example it would be possible in a not too humid climate to pack dried dates in paper. However, this would not be suitable for dried herbs, which would require a plastic packaging system such as polythene or better still polypropylene.

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ANNEX 1: Useful data for calculations

Some SI units

Physical Quantity	SI Unit	Unit Symbol
Energy	Joule	J =Nm
Power	Watt	W = Js^{-1}

Common conversion factors

Imperial	Metric
Volume	
1 ft^3	0.0283 m^3
1 UK Gallon (gal)	4546 cm^3
Volumetric Flow	
1 ft^3 min^{-1} (cfm)	4.72 x 10^{-4} m^3 s^{-1}
Energy	
1 kWh	3.600 MJ
1 therm	105.5 MJ
Power	
1 Horse Power (hp) (British)	745.7 W
1 Btu lb^{-1}	0.2931 W
Calorific Value	
1 Btu lb^{-1}	2.326 kJ kg^{-1}
Density	
1 lb ft^3	16.02 kg m^{-3}

Calorific values

Fuel type	Btu lb^{-1}	KJ / kg
Hydrogen	51980	120900
Methane	21560	50140
Propane	19800	46050
Kerosene	19810	46000
Butane	19650	45710
Octane	19290	44880
Fuel Oil	17800	41400
Coal (5% Ash)	15050 - 15910	35000 - 37000
Coal (10% Ash)	8598 - 9 458	20000 – 22000
Briquettes 30-45% Charcoal Dust 30-45% Chopped Twigs 15-20% Manure	7954	18500
Dry Beach Wood	7610	17700
Black Coffee Husks	7524	17500
Cotton Stalks	7395	17200
Corn Stover	7395	17200
Waste paper balls made from newspaper	6 922	16100
Wood (general)	6 879	16000
Briquettes 50% Straw 50% Manure	6 492	15100
Rice Husk	5 933	13800
Briquettes 40% Straw, 40% Sawdust	5 890	13700

20% Manure		
Briquettes 25% charcoal dust, 25% straw 30% chopped twigs, 20% manure	5 632	13100
Green Beach Wood	5 202	12100
Cow Dung	4 385	10200
Bogasse	3 439 - 8 169	8000 – 19000
Briquettes made from charcoal dust with clay as a binder	1 758	4090
	Btu ft^{-3}	KJ/ m^3
Gas	510	19000

- Specific Heats (at a constant pressure)

	Btu ft^{-3}	KJ kg^{-1} K^{-1}
Air	0.2400	1.005

- Specific Heat of Air (c)

  C = 1 + 1.942 h (KJ kg^{-1} K^{-1}) (where h = absolute humidity of air)

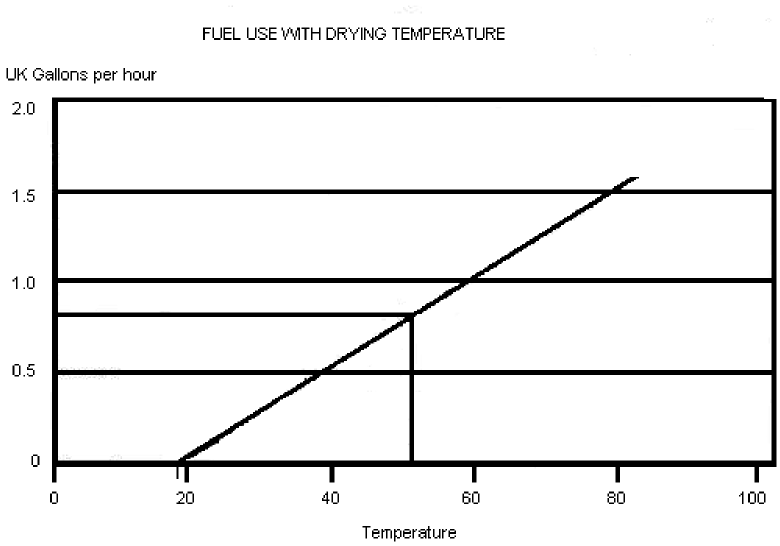
- Densities (at STP)

	lb ft^{-3}	kg m^{-3}
Air	0.0800	1.280

- Variation of latent heat of water with temperature

Temperature °C	Latent Heat (kJ / kg^{-1})
20	2384
40	2326
60	2280
80	2233
100	2210

ANNEX 2: Fuel use graph



The graph shown to the left (and featured earlier in the report) is an easy way of determining the fuel use of the drying system. This graph though is for a particular drying condition of ambient air of 18 °C, RH of 60% and a drying temperature of 50 °C. There will be slight changes depending on the changing ambient conditions. However, for most purposes, the graph shown earlier will be sufficient to obtain approximate fuel consumption values.

If the temperature lift is at about 60 °C, the for example if ambient is 20 °C and the desired drying temperature is 50 °C, the approximate fuel consumption is

$$((50 - 20) / 50) \times 1.6 = 0.8 \text{ gals / hr}$$

However, a simple was to calculate the percentage time the heater is on and hence calculate the average fuel consumption is to measure by observation using a watch.

References and further reading

Drying of Foods, Practical Action Technical Brief
Drying Technologies, Practical Action Technical Brief
Anagi Tray Dryer, Practical Action Technical Brief
Solar Drying, Practical Action Technical Brief
Drying Food for Profit: A Guide for Small Businesses Barrie Axtell, ITDG Publishing, 2002
Producing Solar Dried Fruit and Vegetables for Micro- and Small-scale Rural Enterprise Development Natural Resources Institute, 1996
Drying Food For Profit: A Guide for Small Business, Barrie Axtell, 2002, ITDG Publishing ISBN 1 85339520 X
Setting up a Food Drying Business: A Step-by-step Guide, Fabrice Thuillier, 2002, ITDG Publishing, ISBN 1 85339 498 X
Drying Foodstuffs, Jean Françoia Rozis, 1997, Backuys Publishers
Construction and Use of a Simple Solar Dryer to Preserve Food for Off Season HEDON Household Energy Network
Try Drying It: Case Study, Axtell B, et al, Intermediate Technology Publishing, London, 1991

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